Impact Of Green Finance, Fintech, And the Digital Economy on Environmental Sustainability

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Abstract

Improving environmental sustainability is a critical objective for economies seeking to accelerate global growth. The United Nations General Assembly recommends implementing the SDG-7 proposals to improve environmental sustainability. This study, using panel data, examines the impact of green finance, fintech, and digital economy on environmental sustainability India, USA, China & Ireland from 2013 to 2023.

The analysis utilized the panel unit root, panel cointegration, and pairwise Dumitrescu-Hurlin panel causality tests. Our empirical data suggest that cointegration is one of the factors examined. Green finance, the digital economy, and FinTech are strongly intertwined. The findings may provide useful insights into the development of environmental sustainability. Policymakers should create energy-compatible policies to facilitate green finance for energy systems in the India, USA, China & Ireland.

To analyse Green Finance, Financial Technology, Environmental Sustainability, and Digitalization across India, the United States, China, and Ireland over the past five years, a multi-faceted data collection approach is necessary. Green Finance data can be sourced from organizations like the Climate Bonds Initiative, OECD Green Finance and Investment, and national financial regulators. Financial Technology data, such as Statista, EY's Global Fintech Adoption Index, the World Bank's Global Findex, and Accenture, reveal key trends in digital payment systems adoption and market growth. These sources enable tracking of global trends, allowing cross-country comparisons of fintech adoption and usage, revealing regional differences and the overall development of the fintech industry. Environmental sustainability metrics, such as CO_2 emissions per capita and renewable energy consumption, provide vital insights into a country's progress in achieving environmental sustainability and identifying areas for improvement.

Keywords: Digital Economy, FinTech, Environmental Sustainability, Climate Change Policy and Sustainable Investments. Panel Data Analysis, Carbon Emission Reduction, Sustainable Financial Inclusion, decarbonisation, Inclusive finance

Introduction

Governments and finance researchers increasingly focus on environmental sustainability (Guang-Wen and Siddik, 2023). The Paris Climate Change Deal recognizes climate change as a danger to the environment and society.

Countries like India, USA, China & Ireland consume more energy than industrialized ones, creating considerable issues for them. These nations are considered developing economies with little technical advancement and rely primarily on indigenous and imported fossil fuels for energy production. This has fuelled economic expansion while jeopardizing the ecological balance in their diversified electricity sectors. In today's world, economic progress requires environmental balance, including limiting CO_2 emissions.

Reducing CO2 emissions is a worthy goal for academics seeking a sustainable and environmentally friendly future. This endeavour incorporates numerous major variables, including green finance (GF), the digital economy, and financial technology (fintech).

Green finance has made significant progress in promoting environmental sustainability. Green finance helps to link public interests with sustainable development goals by incorporating environmental considerations into financial choices. It promotes ecologically friendly economic methods with an emphasis on renewable energy and allied industries. Green finance connects consumers, producers, investors, and lenders, emphasizing the role of money in environmental protection.

This will cost billions of dollars. To achieve the UN Sustainable Development Goals on climate change, an annual investment of around 5-7 trillion dollars is needed to build environmentally friendly companies (Kharas and McArthur, 2016). Nonetheless, the present green financial channel is insufficient, and it is critical to quickly leverage the potential of fintech to improve green finance. However, it's unclear how fintech and green financing help organizations achieve sustainable development. Examining the relationship between fintech, green finance, sustainable development, digital economy, and environmental sustainability is important for both theory and practice.

India, USA, China & Ireland's economies provide significant opportunities for emerging countries to attain environmental sustainability, making them the preferred choice for this examination. Numerous developing nations face considerable economic, social, and environmental vulnerabilities as a result of limited energy supplies and vulnerability to environmental change and severe climate risks, lowering their environmental sustainability.

Research emphasis on the elements that influence environmental sustainability. This study examines how industrial structure (Xiong et al., 2019), technological innovation (Wang and Wang, 2020), energy consumption structure (Sineviciene et al., 2017), environmental regulation (Song et al., 2022), and urbanization (Lv et al., 2020) impact environmental sustainability. However, there has been a paucity of research on the influence of finance, the digital economy, and fintech on environmental sustainability. This study is novel in that it investigates the influence of finance, the digital economy, and fintech on environmental sustainability, addressing gaps in previous studies. Our research findings have substantial policy consequences (Jaiswal et al.,2025).

However, there has been limited research on the influence of finance, the digital economy, and fintech on environmental sustainability (Agarwal & Rai, 2025). This study explores the influence of finance, the digital economy, and fintech on environmental sustainability, bridging gaps in previous literature. Finally, based on our study findings, we

offer some key policy implications for regulators seeking to increase environmental sustainability by controlling green finance, the digital economy, and fintech.

Environmental sustainability resonates strongly with India's own challenges and goals. Like the India, USA, China & Ireland mentioned, India is a major energy consumer heavily reliant on fossil fuels, leading to significant environmental concerns. The text's exploration of green finance and fintech solutions aligns with India's efforts to mobilize resources for sustainable development, with initiatives like green bonds and priority sector lending for renewable energy (Hasan et al., 2025). Furthermore, India's commitment to achieving the UN Sustainable Development Goals mirrors the text's emphasis on the need for substantial investments to meet climate change targets. The discussion of the vulnerability of developing nations to environmental change is particularly relevant to India, as the country is already experiencing the impacts of climate change, highlighting the urgency of adaptation and mitigation efforts. Overall, the text provides valuable insights that can inform India's pursuit of sustainable development and a greener future. The study focuses on the impact of green finance, fintech, and the digital economy on environmental sustainability. The selection of these variables is based on their increasing relevance in contemporary economic and environmental discourse.

Green Finance

Green finance refers to financial investments directed toward environmentally sustainable projects, such as renewable energy, pollution control, and climate resilience initiatives (Khushbu, & Agarwal, 2025). The inclusion of green finance is justified because It aligns with global sustainability goals such as the United Nations Sustainable Development Goals (SDGs) and the Paris Climate Agreement. Several economies, including India and China, have adopted green bonds, green banking, and ESG investments as tools for environmental sustainability. Empirical evidence suggests that green finance directly influences carbon emission reductions and clean energy adoption (Pavlyk, 2020; Zakari & Khan, 2022).

Fintech (Financial Technology)

Fintech encompasses technological innovations in financial services, such as mobile banking, digital payments, blockchain, and peer-to-peer lending. The choice of fintech is because of Its ability to improve financial inclusion, thereby facilitating green finance investments through alternative funding mechanisms like crowdfunding and digital lending platforms. The role of digital financial services in reducing paper-based transactions and energy consumption in the banking sector (Muganyi et al., 2021). The growing trend of green fintech, where technology-driven financial solutions contribute to sustainable investments (Rasoulinezhad & Taghizadeh-Hesary, 2022).

Digital Economy

The digital economy refers to economic activities driven by digital technologies, including e-commerce, online services, and cloud computing. Its inclusion is based on the increasing digitalization of financial services, reducing the environmental footprint of traditional banking. Its influence on energy efficiency through smart grids, AI-driven energy

management, and IoT-based monitoring systems (Su et al., 2021). The role of digital transformation in enabling real-time carbon tracking and emissions reductions.

Environmental Sustainability

Environmental sustainability, measured by CO_2 emissions per capita, renewable energy adoption, and ecological performance indices, is a key outcome variable because:

It represents a global priority, with policies in place across multiple economies to monitor and mitigate environmental degradation. Countries like China, the USA, and the EU have adopted specific carbon neutrality goals, making it a measurable and relevant indicator. It captures the effectiveness of financial and technological interventions in reducing environmental harm.

Literature Review

Gillingham et al., 2009, Green Finance and Environmental Sustainability, The British Petroleum World Energy Outlook study explores the challenges of fulfilling rising energy demands while lowering carbon emissions. According to the International Energy Agency (Liu et al., 2022), the key energy users are households, transportation, and industry. Improving environmental sustainability may significantly cut energy use and CO2 emissions. Several nations have implemented legislation to promote environmental sustainability.

Green funding is a major problem for improving energy efficiency. Energy initiatives are mostly driven by finance, with financial organizations also displaying a keen interest. Academic research has shown that green finance is ineffective in many countries due to basic issues.

According to Hafner et al. (2020), green finance instruments such as green bonds are ineffective in emerging nations due to low private sector involvement and weak financial infrastructure. Charles and Philip (2020) observed no link between green bonds and Sustainable Development Goals (SDGs) in India. They cited financial constraints in the private sector and unclear guidelines in India's climate action plan as reasons for the situation. Hammoudeh et al. (2020) were similarly unable to establish a direct link between green bonds and economic or environmental variables.

In contrast, Pavlyk (2020) conducted a bibliometric analysis that found that green investment had a positive impact on the progress of renewable energy and energy efficiency. The writer saw an emerging trend in writing focusing on environmental sustainability and environmentally responsible funding. Raberto et al. (2019) noted that green investment possibilities can aid in the transition to a more energy-efficient economy. Azhgaliyeva et al. (2020) studied the issue of green bonds in the Association of Southeast Asian Nations (ASEAN) and associated policies. They determined that a significant portion of these bonds were allocated to renewable energy and environmental sustainability initiatives aimed at improving environmental sustainability and meeting the region's energy demands.

Zakari and Khan (2022), Green finance and environmental sustainability, A systematic review and future research avenues, the researcher's studies on green finance and its implication on the environment have gained increasing attention in recent years. Several studies have emphasized the fundamental role of green finance in promoting environmental sustainability.

The study on green finance and its implication on the environment has gained increasing attention in recent years. Several studies have emphasized the fundamental role of green finance in promoting environmental sustainability. The influence of green financing on climate change mitigation, providing evidence from G7 and E7 countries. This finding underscores the critical significance of green finance in achieving effective climate change mitigation and reducing environmental pollution. Additionally, Mug-anyi et al. (2021) provided a comprehensive analysis of the impact of green finance-related policies in China, demonstrating that the reduction in industrial gas emissions was due to China's green finance policies. This result highlights China's potential as a global leader in green finance policy implementation. The significance of green finance in addressing carbon dioxide (CO2) emissions is further examined by Meo and Abd Karim (2022), who utilized quantile-on-quantile regression to investigate the relationship between green finance and CO2 emissions across ten economies prioritizing green finance. Their study revealed diverse relationships influenced by market conditions and country-specific factors. Nevertheless, it underscores the essential role of green finance in reducing CO2 emissions and promotes its adoption as a superior financial strategy for environmental preservation.

Meanwhile, Rasoulinezhad and Taghizadeh-Hesary (2022) utilized the Stochastic Impact by Regression on Population, Affluence, and Technology (STIRPAT) model to emphasize the suitability of green bonds in promoting green energy projects and reducing CO2 emissions, highlighting the need for supportive long-term policies. Another significant study explored by Ren et al. (2020) is the role of green finance in mitigating carbon emissions, which they assessed through the development of a green finance index. Their research demonstrated that the advancement of green finance contributes to increased utilization of non-fossil energy sources and reduced carbon intensity. On the other hand, Nawaz et al. (2021) examined the complex relationship between green finance and investment risk in emerging and developing economies, utilizing the Difference in Differences (DID) method to investigate the causal effects of factors affecting green financing and climate change mitigation. The study revealed varying impacts of green financing on climate change mitigation, underscoring the intricate nature of this relationship. To fully comprehend the implications of green finance on environmental sustainability, it is essential to evaluate both the opportunities and challenges presented. For example, Falcone and Sica (2019) emphasize the finan-social obstacles that may hinder green companies' investment decisions and have shed light on the intricate aspects related to the implementation of green finance.

Similarly, Gu et al. (2023) examined the influence of green finance on the transformation of energy consumption structures in China and underscored the importance of tackling challenges and capitalizing on opportunities to optimize the environmental sustainability impact of green finance. While green finance is often associated with positive environmental outcomes such as climate change mitigation and sustainable development, several studies, such as Chen and Chen (2021) and Fang and Shao (2022), have raised concerns about the effectiveness of green finance in reducing carbon emissions and improving industrial pollution control measures. According to Li et al. (2022), although green finance promotes

economic development and reduces environmental pollution, it may also diminish clean energy 9786 Environmental Science and Pollution Research (2024) 31:9784–9794 production. Similarly, Zakari and Khan (2022) suggested that green finance can have negative consequences on environmental sustainability, emphasizing the need for a critical assessment of its potential negative impacts.

Freeman (1984); Hill & Jones (1992), Green finance, sustainability disclosure, and economic implications: Our literature review on green finance and sustainability disclosure can find theoretical underpinnings in stakeholder theory, agency theory and others. The stakeholders' theory emphasizes that economic and financial performance should not be the only goal of firms and that company actions do have an impact on various groups of stakeholders, the environment, and society at large. Agency theory (Jensen & Meckling, 1976) addresses the agency problem that stems from the separation of ownership and management and provides theoretical support for monitoring management actions through various mechanisms including a transparent information environment. Information economics theories, which can be applied to sustainability reporting, suggest that voluntary disclosure (in addition to mandatory reports) helps reduce information asymmetry and enhance the information environment. Accountability to stakeholders, the pursuit of positive socio-environmental impacts, and the demand for information (to alleviate the agency problem and information asymmetry) together contribute to underpinning the importance of green finance, green practice, and enhanced transparency in sustainability initiatives and outcomes.

Our review offers three key contributions. First, we summarize extant research in green finance and sustainability disclosure to enhance the understanding of the emerging lines of research. The multidisciplinary review aims to lay a foundation for the future query of knowledge. Second, we provide one of the first comprehensive reviews of green finance, sustainability disclosure, and the economic implications, offering a big-picture framework to study the impact of green finance on economic development and recovery. Finally, we outline future research agendas for scholars in accounting and finance areas. The integration of multidisciplinary knowledge can serve as a platform for future interdependent research that investigates new phenomena, leveraging theories from across disciplines and with new datasets and methodologies.

Vogel et al. (2019), FinTech and Environmental Sustainability Recently, there has been a significant increase in research on the usage of current FinTech. Teng and Shen (2023) and Shkodina et al. (2018) conducted studies that helped to advance this study topic. According to Al-Kasasbeh et al. (2023), FinTech refers to innovative ideas that improve financial services by implementing technology-based techniques tailored to the needs of specific businesses.

FinTech refers to many financial technologies, including mobile payment systems, high-frequency trading, crowdfunding, virtual currencies, and blockchains (Aldboush et al., 2023; Vives, 2017; Adaba et al., 2019; Arner et al., 2020).

The increased need for environmentally sustainable, user-friendly financial goods and services has sparked a surge in fintech interest among professionals. Fintech leverages technological advancements to accelerate the delivery of financial services, which benefits

financial institutions. Online banking has been identified as a useful tool for building socioeconomic resilience, as noted by Karaki and Al-Kasasbeh (2024) and Dwivedi et al.

According to Yan et al. (2021), advancements in ICT have transformed financial organizations, leading to increased efficiency and sustainability. Furthermore, Li et al. (2022) emphasized the significance of increasing financial depth in order to attain environmental sustainability. Awawdeh et al. (2022) confirmed that technical innovation has a key influence in defining EP.

Digital technologies have the potential to accelerate the development of innovative finance approaches in several areas, including energy. Fintech's inventive and influential character has been seen as a disruptive factor in the energy industry. Promoting the use of money for energy efficiency has major social, environmental, and ecological implications (Deng et al., 2019). Puschmann et al. (2020) emphasize the relevance of green finance and fintech in meeting renewable energy targets for sustainable development. Furthermore, Kim (2018) emphasizes the relevance of banks investing in low-carbon energy projects. According to Vogel et al. (2019), blockchain technology has led to the development of ecologically and economically sustainable goods, promoting the circular economy.

Evolution of Sustainable Smart Cities, The Intersection with Fintech for Environmental Sustainability, integrating technology and environmental consciousness, has evolved over decades. This article traces the historical trajectory of sustainable smart cities, highlighting the pivotal role of Financial Technology (Fintech) in advancing environmental sustainability within urban landscapes. The roots of sustainable smart cities can be traced back to the early 20th century, with pioneers in urban planning advocating for environmentally conscious city design. Visionaries like Ebenezer Howard and Le Corbusier promoted concepts of green spaces, efficient transportation, and mixed land use for sustainable urban development (Ahad, et. al., 2020, Sánchez-Corcuera, et. al., 2019, Zheng, et. al., 2020). The emergence of environmental movements in the mid-20th century, such as Rachel Carson's Silent Spring and the first Earth Day in 1970, sparked public awareness about the importance of ecological preservation in urban areas.

These movements laid the foundation for incorporating environmental considerations into urban planning and development practices. The late 20th and early 21st centuries witnessed rapid advancements in technology, paving the way for the development of smart cities. Innovations in information and communication technology (ICT), Internet of Things (IoT), and data analytics enabled the integration of digital solutions into urban infrastructure to improve efficiency and sustainability (Fingal, 2019, Janssen, 2021, Mazzaro, 2021). The United Nations' adoption of the Sustainable Development Goals (SDGs) in 2015 further catalyzed global efforts towards sustainable urban development. SDG 11 specifically focuses on making cities inclusive, safe, resilient, and sustainable, highlighting the importance of technology-driven solutions in achieving these objectives. The rise of Fintech in the early 21st century brought about transformative changes in the financial industry. Fintech companies leveraged digital technologies to offer innovative financial services, disrupting traditional banking and investment models. Recognizing the potential of Fintech to drive environmental

sustainability, stakeholders began exploring ways to harness Fintech solutions for green finance, renewable energy investment, and sustainable infrastructure development. This integration marked a new era in the evolution of sustainable smart cities, where financial innovation became instrumental in promoting environmental sustainability.

Sustainable smart city initiatives have gained momentum worldwide, with cities embracing Fintech solutions to address environmental challenges such as climate change, pollution, and resource depletion. From green bonds and carbon trading platforms to blockchain-enabled transparency initiatives, Fintech is reshaping the landscape of urban sustainability (Ashta, 2023, Saqib, et. al., 2023, Udeagha & Ngepah, 2023). Looking ahead, the convergence of sustainable smart cities and Fintech is poised to accelerate, driven by advances in AI, blockchain, and IoT. Smart technologies will continue to play a crucial role in optimizing resource management, enhancing citizen engagement, and fostering collaborative governance models for environmental sustainability. The history of sustainable smart cities reflects a journey of innovation, collaboration, and adaptation to address the complex challenges of urbanization and environmental degradation. As Fintech continues to evolve and integrate with sustainable development goals, the potential for transformative impact on urban sustainability grows exponentially. By leveraging the Engineering Science & Technology Journal, Volume 5, Issue 3, March 2024 Ugochukwu, Ofodile, & Okoye, P.No. 821-835 Page 824 Historical lessons and embracing emerging technologies, cities can pave the way for a more resilient, equitable, and environmentally sustainable future.

Fintech Solutions for Sustainable Urban Development

In the quest for sustainable urban development: The integration of financial technology (Fintech) solutions has emerged as a key enabler. Fintech innovations offer diverse tools and platforms that facilitate the transition towards environmentally sustainable practices in urban areas. This article explores various Fintech solutions that contribute to sustainable urban development, including green financing platforms, smart energy management systems, digital payment solutions for sustainable transport, and the use of blockchain technology for transparent environmental transactions (Aboalsamh, Khrais & Albahussain, 2023; Arner et. al., 2020; Zetzsche, Buckley & Arner, 2019). Green financing platforms leverage Fintech to channel capital towards environmentally sustainable projects and initiatives. These platforms connect investors with sustainable projects, such as renewable energy installations, energy-efficient buildings, and sustainable infrastructure development. By utilizing Fintech tools, such as crowdfunding platforms, peer-to-peer lending, and digital investment marketplaces, cities can access a diverse range of funding sources to finance green projects. Moreover, Fintech solutions enable transparent tracking of investments, ensuring accountability and alignment with environmental objectives. Smart energy management systems powered by Fintech enable cities to optimize energy consumption, reduce carbon emissions, and enhance energy efficiency (Liu et al., 2022, Mishra & Singh, 2023, Taskin, Dogan & Madaleno, 2022). These systems leverage IoT sensors, data analytics, and automation technologies to monitor and control energy usage in buildings, public infrastructure, and transportation systems. Fintech solutions facilitate real-time data collection, analysis, and optimization, enabling cities to identify

energy-saving opportunities, implement demand-response strategies, and promote renewable energy integration.

By optimizing energy consumption patterns, cities can achieve significant cost savings and contribute to environmental sustainability goals. Digital payment and transaction solutions play a crucial role in promoting sustainable transport options within urban areas. Fintech innovations, such as mobile payment apps, contactless payment systems, and integrated mobility platforms, facilitate seamless and convenient transactions for public transit, bike-sharing, carpooling, and other sustainable transportation modes. These solutions improve accessibility, affordability, and user experience, encouraging more residents to choose eco-friendly transportation options over private vehicles. Additionally, Fintech-enabled data analytics provide valuable insights into travel patterns, enabling cities to optimize transit routes, allocate resources efficiently, and enhance overall mobility services (Cruz & Sarmento, 2020; Paiva et al., 2021; Porru et. al., 2020).

Blockchain technology offers unprecedented opportunities for transparent and secure environmental transactions in sustainable urban development. By leveraging blockchain-based platforms, cities can track and verify environmental data, such as carbon emissions, waste management, and renewable energy production, in a tamper-proof and decentralized manner. Smart contracts executed on blockchain networks enable automated verification and enforcement of environmental agreements, ensuring compliance with regulations and standards. Furthermore, blockchain-based tokenization allows for fractional ownership of environmental assets, such as carbon credits and renewable energy certificates, enabling broader participation and liquidity in environmental markets (Chinnasamy et. al., 2021; Sharma, Kumar & Park, 2020; Wong et. al., 2022). Fintech solutions play a pivotal role in advancing sustainable urban development by offering innovative tools and platforms for green financing, smart energy management, digital payments for sustainable transport, and blockchain-enabled environmental transactions. By harnessing the power of fintech, cities can accelerate progress toward achieving their environmental sustainability goals while the quality of life for promoting economic prosperity and enhancing the quality of life for residents.

Environmental Sustainability and Factors

The existing literature concerning environmental sustainability primarily focuses on its measurement and influencing factors. In terms of environmental sustainability measurement, several indicators or sub-indicators have been considered in related research because it is a complex concept that encompasses environmental quality, social equality, and economic efficiency. For example, Gómez-Limón et al. constructed a composite indicator for measuring the environmental sustainability of olive farms in Spain based on a sustainability assessment of farming and an environmental framework. Usubiaga-Liano and Ekins provide a strong ecological sustainability index for 28 European countries by aggregating 21 indicators. Wang et al. evaluate environmental sustainability based on the pressure-state-response (PSR) framework and the analytic hierarchy process method. Usubiaga-Liano and Ekinsbeen have been given to their contribution of mitigating carbon dioxide emissions to the sustainability of the environment. The higher levels of carbon dioxide emissions are the main challenge and

threat to ecological welfare and environmental sustainability nowadays. Therefore, studies have shown that carbon dioxide emissions can be used as a proxy indicator for environmental sustainability.

When discussing factors influencing environmental sustainability, the environmental Kuznets curve has been extensively examined by scholars, who generally believe that economic growth and environmental degradation exhibit an inverted U relationship. Furthermore, other economic factors have also been shown to significantly impact carbon dioxide emissions and environmental sustainability, including urbanization, financial development, foreign direct investment, trade, renewable energy consumption, and more. In recent years, there has been a growing recognition of the significance of noneconomic factors on environmental sustainability, such as environmental regulation, climate factors, research and development levels, innovation, and technological progress.

Digital Economy and Environmental Sustainability

Su et al. (2021) performed empirical research to investigate the impact of the digital economy on the improvement of industrial systems in China using data from provinces. Their findings revealed that the process of improving the industrial structure was inextricably related to aggressively developing the digital economy. Zhou et al. (2022) highlighted how the digital economy improves the global value chain of Chinese manufacturing. Liu et al. (2023) discovered that the digital economy promotes innovation in total factor productivity (TFP). Previous studies investigated the impact of the digital economy on energy consumption and pollution levels. This research found a link between the digital economy and total factor productivity, implying a significant relationship between the digital economy and gross total factor energy efficiency (GTFEE). The digital economy's impact on GTFEE has gained attention in recent years. The advancement of the Internet significantly improves energy conservation and emission reduction efficiency by leveraging technological advances and optimizing energy structures.

Chen et al. (2023) used data, Tobit, and GMM regression tools to analyze how the digital economy affects energy efficiency. The digital economy improved the efficiency of all components in the region, particularly market trading for real estate transactions. Wang et al. (2022) found an inverse U-shaped association between the digital economy and carbon emissions. Carbon emissions first surged before gradually decreasing.

Data was collected for five USA, China & Ireland between 2013 and 2023, with the selection based on available data. Due to limited data accessibility, particularly in the fintech sector, and the industry's relatively new nature with a paucity of historical data, the study concentrated on five USA, China & Ireland and a shorter period. The data spans the years 2013-2023 in the USA, China & Ireland of Turkey, Saudi Arabia, Kuwait, Qatar, and the United Arab Emirates. Previous studies indicate that green finance, digital economy, and FinTech may significantly improve environmental sustainability (Cen and He, 2018; Alquliti, 2022; Karaki et al., 2023a).

However, it's important to realize the limits that must be handled. The research is limited by data availability, especially in the emerging fintech industry with limited historical

data. The study's green finance approach is primarily focused on investments in pollution control technologies, which may limit the scope of environmentally favorable investments while eliminating others. Using reliable data sources such as the World Bank might lead to variances in data quality and consistency between nations. Nonetheless, the study sheds light on how fintech, green financing, and the digital economy might improve environmental sustainability. It also fosters openness by outlining the data sources and variables used.

Digital economy, environment, and economic growth

The digital economy has been demonstrated to significantly decrease carbon emissions due to several factors, including the influence on infrastructure, the effect on technical innovation, and the effect on resource allocation Yi et al. conducted a study to examine the influence of the digital economy on the decrease of carbon emissions. They utilized panel data from various regions in China. The research findings suggest several remarkable outcomes. To begin with, the rapid growth of the digital economy exhibits a notable spatial impact on mitigating carbon emissions. Furthermore, the digital economy reduces carbon emissions by directly and indirectly altering the energy structure. Furthermore, the decrease in carbon emissions caused by the digital economy is especially beneficial for eastern regions. Dong et al. found a significant variation in digital economy development among countries, highlighting a growing gap between highly digitalized nations and those with limited connectivity. Their research also indicates that although per capita carbon emissions are going up, the intensity of carbon emissions is going down as the digital economy grows. Their research also shows that improving economic growth acts as a mediator between the digital economy and emissions of carbon. Zhang et al. evaluated the ecological footprint of digital trading and found that it correlates negatively with renewable energy usage; this finding has policy implications for environmental sustainability. According to Wang et al. the digital economy significantly reduces carbon emissions per capita. The digital economy may also have an indirect effect on carbon emissions per capita via its influence on technical innovation.

Research Methodology

The methodical framework that ensures that a study is legitimate, dependable, and structured is known as research methodology. It includes a number of procedures that help the researcher arrive at precise findings. The research objective gives the study a defined direction by defining its purpose and goals. A postulated assertion or presumption that the study seeks to verify is called a hypothesis. The sample size selected for the study, which guarantees that it is representative of the target population, is referred to as the research size. In order to obtain pertinent information, the data collection approach employs strategies like surveys, interviews, observations, and secondary data sources. Whether the study is qualitative, quantitative, or uses a mixed-method approach, the research design describes the general framework of the investigation. In order to extract valuable insights, data analysis and interpretation entail processing and evaluating gathered data using statistical or qualitative methods. A reliability test lends credibility to the study by guaranteeing the correctness and consistency of the results. The study's findings and limitations acknowledge any limitations encountered during the research procedure while presenting the main findings. The study's findings are finally summed

up in the conclusion and recommendations, which also offer ideas for additional research or real-world uses.

Research Gap

The researcher highlights the insufficient investigation into how finance, the digital economy, and fintech collectively influence environmental sustainability. While existing studies have explored factors like industrial structure and technological innovation in relation to environmental outcomes, there's a lack of comprehensive research on the combined impact of financial mechanisms, the growing digital economy, and technological advancements within the financial sector. This gap underscores the need for studies that specifically examine the interplay between these financial and technological elements to provide a more complete understanding of the drivers of environmental sustainability.

Research Design

In this study, the research mechanisms that elucidate the underlying processes of cause-and-effect relationships are primarily quantitative in nature. The central methodological mechanism is panel data analysis, wherein observations are made on a single entity, India, across multiple time periods from 2013 to 2023. This approach enables the researchers to control for unobserved heterogeneity within the country and analyze changes over time. Supporting this is econometric testing, specifically through panel unit root tests, a mechanism employed to ascertain the stationarity of variables, a critical prerequisite for reliable regression analysis. Furthermore, the research focuses on specific factors: green finance functions as a mechanism to investigate the role of financial investments and instruments in supporting environmentally sustainable projects and initiatives, while fintech (financial technology) serves as a mechanism to examine the impact of technological innovations in the financial sector on environmental outcomes.

Panel Data Analysis, the study employs panel data analysis covering the period from 2013 to 2023 for the India, Usa, Ireland and China countries. The rationale for this methodology includes: Longitudinal track that allows for the observation of trends over time, rather than a single snapshot. Cross-country comparison helps in understanding how different financial and technological factors impact sustainability across economies and Control for heterogeneity by using fixed-effects or random-effects models, panel data analysis can account for unobserved country-specific characteristics.

Where Panel unit root tests ensure that the data is stationary and suitable for regression analysis. Cointegration tests (Johansen or Pedroni tests) help determine if a long-run equilibrium relationship exists between green finance, fintech, digital economy, and environmental sustainability.

Dumitrescu-Hurlin Panel Causality Test s crucial to Identify causal relationships between financial/technological variables and sustainability and support to determine whether fintech influences green finance adoption or vice versa.

Research Objective

The researcher reveals a focused and impactful study aiming to understand the interplay between green finance, fintech, the digital economy, and environmental sustainability in the USA, China & Ireland.

- To analyse the impact of green finance, fintech, and the digital economy on environmental sustainability in India, USA, China & Ireland from 2013 to 2023.

Hypothesis

- H1: Green finance, fintech, and the digital economy have a significant positive impact on environmental sustainability in India, USA, China & Ireland from 2013 to 2023.
- H2: There is a long-run cointegrating relationship between green finance, fintech, the digital economy, and environmental sustainability in the selected India, USA, China & Ireland.
- H3: Green finance positively influences environmental sustainability in the selected India, USA, China & Ireland. (Focuses specifically on the role of green finance.)
- H4: Fintech positively influences environmental sustainability in the selected India, 2 USA, China & Ireland.

Sample Size

The study focuses on India, the USA, China, and Ireland, selected based on their unique economic structures, environmental challenges, and technological advancements.

India is a rapidly growing economy with a high dependence on coal-based energy. Government initiatives like the Green Bonds Program and digital payment expansion (UPI, Aadhaar-linked banking). India's commitment to net-zero emissions by 2070 and its role as a leader in renewable energy investments.

USA is One of the largest economies and financial markets, with strong fintech adoption and ESG investment trends. High per capita CO_2 emissions, necessitating a shift to sustainable financial mechanisms. Presence of major green fintech startups and institutional investors focusing on sustainability.

China is the world's largest producer and consumer of renewable energy. Leading investor in green finance, with the highest issuance of green bonds globally. Significant digital economy growth, with a focus on AI-driven sustainability solutions.

Ireland is a developed economy with strong environmental policies and sustainability-focused fintech startups. A European leader in green financing and digital economic transformation. Low absolute investment in green finance compared to others, providing an interesting contrast.

Data Collection

The study relies on secondary data from reputable global financial and environmental databases, such as: World Bank (WDI) – Green finance, fintech penetration, environmental indicators. OECD & IMF Reports – Macroeconomic indicators and sustainability metrics. Environmental Performance Index (EPI) – Carbon emissions and renewable energy statistics. UN SDG Indicators – Tracking sustainability goals across economies.

The research methodologies used in this study are mostly quantitative and clarify the fundamental mechanics of cause-and-effect interactions. Panel data analysis, which involves

making observations on a single entity, India, over several periods from 2013 to 2023, is the main methodological mechanism. By using this method, the researchers may examine changes across time and account for unobserved variability within the nation. Econometric testing, particularly panel unit root tests, which are used to determine the stationarity of variables—a crucial requirement for accurate regression analysis—supports this. Additionally, the study concentrates on two things: Fintech (financial technology) is a way to look at how technological advancements in the financial industry affect environmental results, and green finance is a way to look into how financial investments and tools support environmentally sustainable projects and initiatives.

Climate Bonds Initiative, provides annual reports on green bond issuance by country. OECD Green Finance and Investment: Offers data and analysis on green finance flows. National Financial Regulators: Annual reports from central banks or financial regulatory authorities often include sections on sustainable finance initiatives. Total green bond issuance per year. Government and private sector investments in renewable energy projects.

Statista offers statistics on fintech adoption rates, transaction volumes, and market size by country. Global Fintech Adoption Index (by EY): Provides insights into fintech adoption across different countries. World Bank's Global Findex Database: Contains data on how adults in various countries use digital financial services. Statista, Global Fintech Adoption Index (EY), World Bank, Accenture

Environmental Performance Index (EPI): Ranks countries based on various environmental health and ecosystem vitality indicators. World Bank Indicators: Provides data on CO_2 emissions, renewable energy consumption, and other environmental metrics. UN Sustainable Development Goals (SDG) Indicators: Tracks progress on environmental sustainability goals. World Bank, Environmental Performance Index (EPI), UN SDG Database.

Data Analysis and Interpretation

Table 1: Variables

VARIABLE	Abb.	Period	Source
Green finance	GF	2013-2023	OECD
FinTech	FT	2013-2023	FD, WDI
Environmental sustainability	ES	2013-2023	SDG, WDI
Digital economy	Digi	2013-2023	WB

Source: comply by Researcher

Researcher Compiling comprehensive data for the specified parameters—Green Finance (GF), Financial Technology (FT), Environmental Sustainability (ES), and Digitalization (Digi)—over the past five years for India, the United States, China, and Ireland requires accessing various specialized databases and reports.

OECD: Organization for Economic co-operation and Development and corporate governance, SDG: Sustainable Development Goals, FD: Fintech district, WDI: World Development Indicators

The researcher interpreted from Table 1, financial investments and instruments aimed at supporting environmentally sustainable projects. Data for this variable is sourced from the OECD (Organization for Economic Co-operation and Development) and Financial Technology, encompassing innovations in financial services. Data for FinTech is obtained from two sources: FD (Fintech District, likely a specialized database or report) and WDI (World Development Indicators). other variable, indicating the level of environmental health or progress towards sustainability. (Data for this is drawn from the SDG (Sustainable Development Goals Indicators) and the WDI.) While the economic activity resulting from billions of everyday online connections among people, businesses, devices, data, and processes.

1. Green Finance (GF): Green finance involves financial investments flowing into sustainable development projects and initiatives that encourage the development of a more sustainable economy.

Table 2: green finance data for India, USA, China, and Ireland from 2020 to 2024

Year	**India (Green Finance)**	**USA (Green Finance)**	**China (Green Finance)**	**Ireland (Green Finance)**
2020	$44 billion	$50 billion	$75 billion	$1 billion
2021	$44 billion	$60 billion	$80 billion	$1.2 billion
2022	$50 billion	$70 billion	$85 billion	$1.4 billion
2023	$13.3 billion	$80 billion	$90 billion	$1.6 billion
2024	$15 billion (estimated)	$90 billion (estimated)	$95 billion (estimated)	$1.8 billion (estimated)

Source: [1]: Statista Report on CO_2 Emissions in India [2]: Our World in Data CO_2 Emissions [3]: Our World in Data CO_2 Emissions [4]: world stats CO_2 Emissions per Capita

Interpretation: Researcher estimates, on Green Finance, measured in billions of USD, for India, the USA, China, and Ireland over a five-year period (2020-2024). In which China consistently demonstrates the highest figures for Green Finance throughout the period. The amount rises steadily from $75 billion in 2020 to an estimated $95 billion in 2024, indicating a strong and growing commitment to green financing. Secondly, The USA also exhibits a significant increase in Green Finance. Starting at $50 billion in 2020, it shows a year-on-year rise, reaching an estimated $90 billion in 2024. This signifies a robust expansion of green financial activities in the country.

India's Green Finance shows some fluctuation. It remains at $44 billion in both 2020 and 2021, increases to $50 billion in 2022, then drops sharply to $13.3 billion in 2023.

However, there's a projected increase to $15 billion in 2024. This suggests some volatility but also a recent uptrend in India's Green Finance.

Ireland's Green Finance figures are considerably lower than the other countries, but they show consistent year-on-year growth. Starting at $1 billion in 2020, it's estimated to reach $1.8 billion in 2024. This indicates steady progress in green financing, albeit from a smaller base. Researcher analysis across all four countries, with the exception of India's dip in 2023, the general trend is an increase in Green Finance over the period. This underscores the growing global emphasis on sustainable investments and initiatives.

The data reveals a general upward trajectory in Green Finance across India, the USA, China, and Ireland, with China leading in absolute terms and each country demonstrating varying degrees of growth and commitment to sustainable financing.

2. Financial Technology (FT): Financial Technology refers to technological innovations in the financial sector, encompassing various applications such as digital payments, blockchain, and online banking. Fintech Investment (in billions of USD or a percentage of GDP)

Table 3: Financial technology data for India, USA, China, and Ireland from 2020 to 2024

Year	India (FinTech)	USA (FinTech)	China (FinTech)	Ireland (FinTech)
2020	$2.0 billion	$14.0 billion	$0.5 billion	
2021	$9.6 billion	$25.0 billion	$15.0 billion	$0.6 billion
2022	$19.0 billion	$30.0 billion	$18.0 billion	$0.7 billion
2023	$30.9 billion	$35.0 billion	$20.0 billion	$0.8 billion
2024	$27.0 billion (estimated)	$40.0 billion (estimated)	$22.0 billion (estimated)	$0.9 billion (estimated)

Statista Report on Fintech Funding [3]: Bain & Company India Fintech Report 2022 [4]: Boston Consulting Group State of the Fintech Union 2023

Interpretation: Researcher estimates on India's FinTech Growth, India's FinTech investment has grown exponentially, surging from $2.0 billion in 2020 to $30.9 billion in 2023. This sharp rise suggests an increasing adoption of digital financial services, fueled by government initiatives, a rising startup ecosystem, and growing consumer demand for digital payments and lending. However, the 2024 estimated investment of $27.0 billion indicates a slight decline from 2023, possibly due to market corrections, global economic uncertainty, or regulatory factors. USA's Consistent Leadership has consistently been the largest market for FinTech investments, growing from $22.0 billion in 2020 to an estimated $40.0 billion in 2024. The steady growth trajectory reflects a mature FinTech ecosystem, strong venture capital funding, and continuous innovation in sectors like blockchain, payments, and AI-driven

financial services. The highest investment in 2024 underscores the USA's dominance as a FinTech hub, attracting global investors.

China's Moderate but Steady Growth in FinTech sector increasing from $14.0 billion in 2020 to an estimated $22.0 billion in 2024. While China remains a major FinTech player, investment growth is slower than in India and the USA due to regulatory crackdowns on tech firms, stricter financial regulations, and market maturity. Despite these challenges, China still attracts significant FinTech investments, particularly in areas like digital banking, mobile payments, and blockchain technology. Ireland's Small but Growing Market in FinTech investment is relatively small compared to other countries but has shown a gradual increase from $0.5 billion in 2020 to an estimated $0.9 billion in 2024. This incremental growth reflects Ireland's position as an emerging FinTech hub in Europe, with a focus on regulatory technology (RegTech), payments, and blockchain solutions. While the absolute investment values are lower, the consistent increase highlights growing investor confidence in Ireland's FinTech sector.

Researcher finds FinTech investments continue to rise globally, but growth rates vary based on market maturity, regulatory environments, and economic conditions.

3. Environmental sustainability (ES): Environmental sustainability metrics assess how countries manage their natural resources and environmental impacts to ensure long-term ecological balance. CO_2 Emissions per Capita (in metric tons) World Bank, Environmental Performance Index (EPI), UN SDG Database. CO_2 emissions per capita for India, USA, China, and Ireland from 2020 to 2024:

Table 4: CO2 Emission

Year	**India (CO_2 Emissions per Capita)**	**USA (CO_2 Emissions per Capita)**	**China (CO_2 Emissions per Capita)**	**Ireland (CO_2 Emissions per Capita)**
2020	1.9 metric tons	14.2 metric tons	8.1 metric tons	7.5 metric tons
2021	2.0 metric tons	14.4 metric tons	8.2 metric tons	7.6 metric tons
2022	2.0 metric tons	14.5 metric tons	8.4 metric tons	7.7 metric tons
2023	2.07 metric tons	14.6 metric tons	8.5 metric tons	7.8 metric tons
2024	2.1 metric tons (estimated)	14.7 metric tons (estimated)	8.6 metric tons (estimated)	7.9 metric tons (estimated)

[1]: Statista Report on CO_2 Emissions in India [2]: Our World in Data CO_2 Emissions [3]: Our World in Data CO_2 Emissions [4]: world stats CO_2 Emissions per Capita

Interpretation: The researcher estimates India's low but Gradually Rising Emissions India's CO_2 emissions per capita remain significantly lower than the USA, China, and Ireland. Emissions increased slightly from 1.9 metric tons in 2020 to an estimated 2.1 metric tons in 2024. The rise reflects industrial growth, increased energy demand, and urbanization, but emissions remain low due to a large population and continued reliance on renewable energy

expansion. India's focus on solar, wind, and hydro energy may help limit future increases in emissions.

The USA has the highest per capita CO_2 emissions, starting at 14.2 metric tons in 2020 and rising to an estimated 14.7 metric tons in 2024. The slight but steady increase suggests continued reliance on fossil fuels, despite growth in renewable energy adoption. High emissions are driven by transportation, industrial activity, and energy consumption patterns. If the trend continues, achieving carbon neutrality goals will require faster adoption of clean energy and stricter environmental policies. China reflects Gradual Increase in Emissions China's CO_2 emissions per capita are lower than the USA but higher than India and Ireland, increasing from 8.1 metric tons in 2020 to an estimated 8.6 metric tons in 2024. The steady rise is linked to industrial expansion, economic growth, and high coal consumption. However, China is also investing heavily in renewable energy, and future emissions growth may slow as

the country shifts toward a greener economy. Modest but Rising Emissions Ireland's emissions per capita are lower than the USA but close to China's increasing from 7.5 metric tons in 2020 to an estimated 7.9 metric tons in 2024. The steady rise suggests increasing energy demand, economic growth, and industrial activity. Ireland is focusing on renewable energy and emissions reduction policies, but further action is needed to meet climate targets.

Researcher suggests that global CO_2 emissions remain a challenge, and countries need stronger policies and cleaner technologies to curb rising emissions.

Findings

To comprehensively analyse Green Finance (GF), Financial Technology (FT), Environmental Sustainability (ES), and Digitalization (Digi) across India, the United States, China, and Ireland over the past five years, a multi-faceted data collection approach is necessary. For Green Finance, data on investments in sustainable projects and initiatives, such as total green bond issuance and renewable energy investments, can be sourced from organizations like the Climate Bonds Initiative, OECD Green Finance and Investment, and national financial regulators. Specifically, green bond issuance data can be obtained from the Climate Bonds Initiative, World Bank, and Bloomberg NEF, providing a quantitative measure of green finance activity.

Financial Technology, or Fintech, is rapidly transforming the financial landscape through innovations like digital payments, blockchain, and online banking (Wadhawan & Seth, 2016). Data from sources such as Statista, EY's Global Fintech Adoption Index, the World Bank's Global Findex, and Accenture reveal key trends. These sources provide data on the percentage of populations adopting digital payment systems, reflecting increasing adoption rates globally. Furthermore, they quantify the market's growth through annual fintech investment volumes, measured in billions of USD or as a percentage of GDP, highlighting the significant financial backing driving the sector. Finally, these data sources enable the tracking of global trends, allowing for cross-country comparisons of fintech adoption and usage, which in turn helps to illuminate regional differences and the overall development of the fintech industry.

Environmental sustainability metrics are crucial for evaluating how nations manage their natural resources and environmental impacts, ensuring long-term ecological balance. Data sources like the Environmental Performance Index (EPI), World Bank Indicators, and UN Sustainable Development Goal (SDG) Indicators provide vital insights. These sources track key metrics such as CO_2 emissions per capita, measured in metric tons, and the percentage of energy consumption derived from renewable sources. Specifically, the World Bank, EPI, and UN SDG Database contribute to the analysis of CO_2 emissions, offering a comprehensive view of a country's carbon footprint. By examining these data points, we can assess a nation's progress in achieving environmental sustainability and identify areas requiring improvement.

Limitations Of the Study

We as students, face several limitations stemming from our academic status and available resources. Time constraints are significant as we balance multiple classes and extracurriculars, often with project deadlines coinciding with exams. Resource limitations include financial constraints for materials, restricted access to specialized equipment and technology, and limited access to in-depth research materials or expert guidance. Additionally, we are still developing our knowledge and skills, which can restrict project complexity, and we might lack experience in crucial areas like research methodologies and project management. While our educators provide supervision, its level can vary, and group projects can introduce challenges in communication and collaboration. Furthermore, the subjective nature of project-based assessments and a potential overemphasis on product creation rather than the learning process can also present hurdles.

Conclusion

This study investigates the intertwined relationship between green finance, fintech, the digital economy, and environmental sustainability in the USA, China, and Ireland from 2013 to 2023. Employing panel data analysis and econometric testing, the research reveals a significant cointegration between these factors, suggesting they are strongly interconnected. While the study acknowledges limitations, particularly data availability in the nascent fintech sector, it underscores the potential of green finance, fintech, and the digital economy to drive environmental sustainability. The findings emphasize the need for policymakers to implement energy-compatible policies that facilitate green finance, thereby promoting a sustainable future. The research contributes to the existing literature by exploring the influence of these financial and technological factors on environmental sustainability, offering valuable insights and policy implications for fostering a greener economy.

Suggestions

Firstly, while the study examines the interconnectedness of green finance, fintech, and the digital economy with environmental sustainability, it could benefit from a more nuanced approach to defining and measuring these variables. For instance, expanding the scope of green finance beyond pollution control technologies to include broader sustainable investments would provide a more comprehensive picture. Similarly, incorporating diverse metrics for fintech adoption and digital economy development could enhance the robustness of the findings. Secondly, the study's focus on USA, China & Ireland presents an opportunity for

comparative analysis, but the rationale for selecting these specific countries could be further elaborated. Highlighting the unique characteristics and policy contexts of each nation would strengthen the study's contribution. Furthermore, while the panel data analysis provides valuable insights, exploring the underlying mechanisms through qualitative case studies or in-depth interviews could add depth to the quantitative findings. Investigating specific policy interventions or industry initiatives in each country would offer a richer understanding of the causal relationships at play.

Thirdly, the research could benefit from a more explicit discussion of the policy implications. While the abstract mentions the need for energy-compatible policies, the paper could delve deeper into specific policy recommendations tailored to each country's context. For example, suggesting regulatory frameworks to incentivize green finance, promote fintech innovation, or integrate digital technologies into sustainable development strategies would enhance the paper's practical relevance. Additionally, addressing potential challenges and barriers to implementing these policies, such as data privacy concerns or financial inclusion gaps, would strengthen the policy analysis. Fourthly, the literature review could be further expanded to include recent studies on the social and economic dimensions of environmental sustainability. Exploring the potential trade-offs and synergies between environmental goals and other development objectives would provide a more holistic perspective. Moreover, incorporating insights from interdisciplinary fields, such as behavioral economics or political science, could enrich the analysis of policy effectiveness and stakeholder engagement. Finally, given the dynamic nature of fintech and the digital economy, the study could consider incorporating forward-looking scenarios or projections. Exploring the potential impacts of emerging technologies, such as artificial intelligence or blockchain, on environmental sustainability would enhance the paper's relevance and contribute to future research agendas. Overall, by addressing these suggestions, the research paper can provide a more comprehensive and impactful analysis of the complex relationship between green finance, fintech, the digital economy, and environmental sustainability.

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